Agent-Based and Aggregate Modeling: Tradeoffs & Limitations

Nathaniel Osgood

April 4, 2011

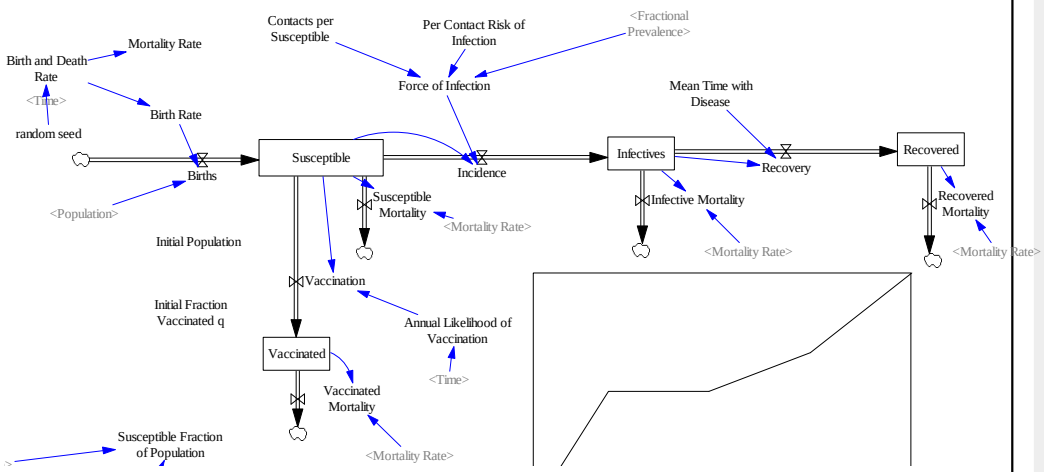
Distinctions

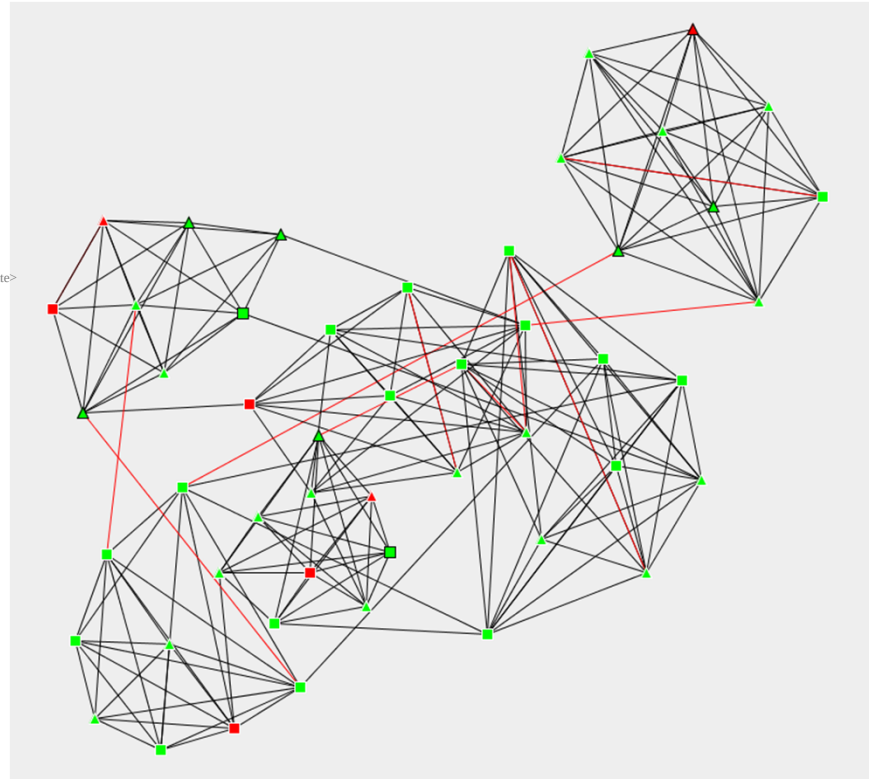
- Inherent, e.g.
  - Qualitative vs. Quantitative
  - Static vs. Dynamic
  - Stochastic vs. Deterministic
  - Capacity to understand single scenario vs. range of scenarios
  - Magnitude of computational resources required
    - Interactive or not
  - Under vs. over-determined calibration
  - Ability to calibrate to/make behaviour depend on individual history
- Important software skills mediation
  - Required level of software development sophistication

Dynamic Models for Health

- Classic: Aggregate Models
  - Differential equations
  - Population classified into 2 or more state variables according to attributes
  - |State Variables|,|Parameters| << |Population|
- Recent: Individual-Based Models
  - Governing equations approach varies
  - Each individual evolves
  - |State Variables|,|Parameters| $\propto$ |Population|

Contrasting Model Granularity





Granularity Selection: Problem Specific

- Selection of granularity is a function of question that are asking – not of the "*true nature of the system*"
- Quanta of most obvious system components may not align with needs for insight
  - May gain benefits from higher-level representation
    - Many high-level behavior of complex systems can be explained with very simple models
    - Often gain greater insight from simpler model: Cf Gas laws vs. lattice gas model
  - May wish to seek lower level model
    - Small infection spread model : Characterization at level of immune response rather than monolithic person

Myth of Individual-Based Models as "Modeling from the Bottom Up"

- A single person is a natural locus of description
  - Presents for care
  - Lives
  - Dies
  - Coupled internal systems
- But the world has no natural "bottom"
  - It is frequently desirable to include within a person a great deal of "within the skin" detail
- The issues of model depth & breath are just as pressing in individual-based models as in aggregate modeling

Contrasting Benefits

Aggregate Models

- Frequently, easier
  - Construction
  - Calibration
  - Parameterization
  - Formal analysis (Control theoretic & Eigenspace techniques)
  - Understanding
- Performance
  - Lower baseline cost
  - Population size invariance
- Less pronounced stochastics
  - Less frequent need for Monte Carlo ensembles
- Quicker construction, runtime $\Rightarrow$More time for understanding, refinement

Individual-Based Models

- Better fidelity to many dynamics
- Stronger support for highly targeted policy planning
- Ability to calibrate to & validate off of longitudinal data
- Greater heterogeneity flexibility
- Better for examining finer-grained consequences
  - e.g. transfer effects w/i pop.
  - Network spread
- Simpler description of some causal mechanisms

Key Needs Motivating Individual-Based Modeling

- Need to calibrate against information on **agent history**
- Need to capture **progression** of agents **along multiple pathways** (e.g. co-morbidities)
- Wish to characterize **learning by and/or memory** of agents based on experience, or **strong history dependence** in agents
- Need to capture distinct **localized perception** among agents
- Seeking to intervene at points in, change behavior on, explain phenomena over or explain dynamics **across networks**
- Seek **distinct interventions for** many **heterogenous categories**
- Need to **capture impact** of intervention across **many categories**
- When it is much simpler to **describe behavior at indiv. level**
- Seek **flexibility** in exploring different **heterogeneity dimensions**
- **Needs of stakeholders** to engage with individual-based models
- Want to describe behaviour at **multiple scales**

Key Needs Motivating Aggregate-Based Modeling

- Need to **execute quickly** (e.g. for user interaction)
- Understand/describe system behaviour across **all possible values for parameters**
  - Seeking to mathematically **analyze the model** (e.g. to determine location or stability of equilibria)
  - To determine shape of **all possible trajectories**
- Want to **use mathematical tools**, such as control theory to identify high-leverage parameters, optimal policies
- Need to **extensively calibrate to much historic data**
- **Desire of stakeholders** to work at higher level
- Behavior for different subgroups **differs only in degree**
- No recourse to **software engineering knowledge**
- **Lack of detailed knowledge** of network structure/ individual-level behaviour/Individual-level data